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RESIN BONDED MOLD AND DIE PRODUCTION TECHNOLOGY

J. RONALD RUSSELL
ROCK ISLAND ARSENAL

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FINAL REPORT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program was to develop low-cost techniques using commercially available epoxy resins to produce molds and dies for small-sized, short-run plastic parts, rubber parts, and investment casting patterns. Efforts to produce epoxy molds and acceptable injected wax patterns were successful. Attempts to produce epoxy molds for plastic injection were only marginally successful, as very few acceptable components could be produced in these dies. However, expertise is commercially available for the over

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fabrication of epoxy tooling for plastic injection. Techniques for the successful fabrication of rubber compression molds and rubber components were established by earlier efforts. Resin bonded mold fabrication substantially reduces tooling costs and lead time for short run and prototype work.

FOREWORD

This final report was prepared by J. Ronald Russell, Arsenal Operations Directorate, Rock Island Arsenal. The work was performed by John Jugenheimer and William Barglof, former project engineers, and J. Ronald Russell, subsequent project engineer.

This project was accomplished as part of the US Army manufacturing technology program. The primary objective of this program was to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

ACKNOWLEDGMENT

The author hereby acknowledges the unpublished efforts of Mr. Dale Maas, foreman of the Rubber, Plastics Molding and Textile Department at Rock Island Arsenal. This work involved the successful application of resin bonded mold tooling techniques for the production of rubber components.

1. INTRODUCTION

The fabrication of metal dies for prototype and short run production orders by conventional die sinking methods is both costly and time consuming. The most costly item for the short-run production of investment castings, plastic, and rubber components is the die. Often times the cost and long lead time for such dies is prohibitive for limited production type work. Short-run production orders of five hundred pieces or less do not always require complete metal dies. Epoxy resin plastics can be used to reduce the time and expense for the production of dies. The application of resin bonded tooling to injection and compression molding was undertaken to establish process techniques for Rock Island Arsenal's die-sinking department.

Preliminary project work in this area produced an epoxy mold and plastic sample part of the XM59 rear sight ring. An epoxy mold used for wax injection produced fifteen lathe way wipers by investment casting. In both cases, the epoxy mold ultimately failed, but not until fifteen components had been produced. These earlier efforts demonstrated the feasibility of method. A program was established to refine epoxy tooling techniques for the production of molds.

2. OBJECTIVES

The objective of this project was to establish the manufacturing methods and technology required to produce less costly dies for prototype and short-run production work for investment casting, plastic and rubber components. Commercially available epoxy thermoset plastic casting and tooling materials were used in the selection of the most suitable materials for the fabrication of these type of molds.

3.0 PROCEDURE

The project was divided into three tasks concerned with the fabrication of epoxy molds. Each task involved the fabrication, testing and evaluation of dies for the production of:

1. Investment wax patterns for investment casting.
2. Plastic components.
3. Rubber compression molded components.

Small components and epoxy tooling materials were selected for each task. A metal two-halve pattern was machined that accounted for recommended shrink tolerances and located to a match plate. Either a two-part aluminum die was fabricated with a cavity in each half large enough to serve as a casting cavity for the mold or a commercially supplied standard die base with cavities already machined was used. The pattern and plate was then assembled to the metal die base and each half of the epoxy mold was poured. In cases where it was advantageous, metal inserts were added to the cavity. After the epoxy molds were cured, the patterns were removed and a minimal amount of machining was completed for sprue, riser, air vents and matching the molds by grinding the surfaces parallel.

3.1 MATERIAL SELECTION

Primarily, the products of two commercially available epoxy tooling material suppliers were used to fabricate molds. These suppliers were Devcon Corporation, Danvers, Massachusetts, and Ren Plastics, Lansing, Michigan.

The products Devcon C and Devcon Plastic Steel B were selected for use in this project according to manufacturer's recommendations and physical properties related to the materials specified for the particular components. Devcon C exhibited more favorable properties over the Devcon Plastic Steel B due to its higher strength at elevated temperatures, greater thermal conductivity, higher heat deflection temperature and lower viscosity. The Devcon C contains approximately 80% aluminum with the remainder as epoxy resin and modifiers. This material was heat cured to obtain maximum physical properties.

The Ren Products RP3269-1 Casting Epoxy was selected for the fabrication of molds for investment wax injection. This epoxy is an aluminum filled resin of lower viscosity than Devcon C (4,600 cps vs. 10,000 cps @ 212^{o}F as listed by manufacturer's product information in Table 1). The lower wax injection temperature of 165^{o}F and nozzle pressure of less than 800 psi as compared to plastic injection temperatures between 300^{o}F to 600^{o}F and injection pressures between 1000 psi to 4000 psi permitted the use of a more readily castable and curable epoxy. RP3269-1 did not require heating and mixing in a double boiler as did the Devcon C. The entrapment of air in the form of air bubbles during casting and curing did not present itself as a problem with RP3269-1. However, a vacuum oven is used with this product to insure the removal of any moisture and air retained during casting. For applications where Devcon C is required, a vacuum oven followed by a lengthy heat cure is required.

The selection of epoxy resin tooling for injection and compression molding requires an evaluation of temperatures, pressures, abrasive effects of materials injected, number of components required and the castability of the resin being considered. The Ren RP3269-1 epoxy was found to be suitable for investment wax injection, but not for plastic injection in this project.

3.2 INVESTMENT WAX INJECTION MOLDS

The two-cavity mold shown in Figure 1 was produced for the M8C Spotting Rifle Hammer component, Part Number 7266361. This mold was cast from Devcon Plastic Steel B which contains approximately 80% steel and 20% epoxy resins. In order to contain the epoxy a two-halve aluminum die base was fabricated with two rectangular cavities large enough to accommodate casting epoxy over the attached pattern halves. Marketter's J3 investment wax was injected into the mold using a model 50 Tempcraft Veri-Flex wax injector. The wax was injected at 800 psi nozzle pressure at 165^{o}F with a cycle time of three minutes. The steel filled epoxy mold successfully produced wax patterns for this component.

A second mold for the M8C Spotting Rifle Hammer was prepared from Devcon Flexane. This molding material is a rubber-like room temperature curing urethane. Investment wax was hand poured into this mold since the mold material was too soft to withstand machine injecting pressures. Results were not favorable. Because of the materials low heat conductivity with subsequent long cooling time, this method was abandoned.

A mold for a M8C Spotting Rifle regulator Lock Nut, Part Number 7266831 shown in Figure 2 was produced from Devcon C epoxy. This four-cavity mold was cast in the same type rectangular cavity of an aluminum die base as the hammer component. Investment wax patterns were produced successfully at a nozzle injection pressure of 750 psi at 160°F with a two-minute cycle time. A comparison of the two molds indicated a slight advantage to the resultant surface detail and finish of the aluminum filled epoxy. Both types of resin bonded molds were acceptable for short-run production work. From the successful results obtained from the fabrication of these molds, production die fabrication of epoxy molds was initiated. Epoxy molds for the list of components in Table 2 were produced for production orders. Approximately 40,000 pieces have been produced in the investment casting area from the application of epoxy tooling. One production mold in particular (shown in Figure 3) for a Humping Block component, Part Number 9198702, produced 8,000 investment wax patterns before a crack developed. The mold was recast with REN RP3269-1 epoxy.

3.3 EPOXY MOLDS FOR PLASTIC INJECTION

The two-part epoxy mold shown in Figure 4 was produced for the M16 Rifle Safety Flag component, Part Number 8448666. A standard commercially available 5" x 6" D-M-E metal mold base with insert cavities was used for efforts in this area. A steel two-halve pattern was fabricated and located to opposite sides of a match plate and assembled to the die base cavity. One half of the mold was cast with Devcon C and the other half with REN RP3269-1. Both materials produced molds with acceptable surface detail and finish. A 0.030 inch diameter runner and a 0.003 inch diameter air vent were the only machining operations performed on the mold. Low density polyethylene was injected into the mold with a model 70VC105 Frohring Mini-Injector. Injection pressures were gradually increased from 1000 psig to 1200 psig with various injection times and nozzle temperatures. Only a few acceptable pieces were produced using the injection parameters of:

Injection pressure	-	1200 psig
Injection time	-	29 sec.
Cycle time	-	150 sec.
Nozzle temperature	-	330°F
Cylinder temperature	-	360°F

Flash appeared on the component as the plastic eroded the REN RP3269-1 half of the mold. The runner area of this half notably eroded and on the thirteenth trial, this side cracked preventing any further injection. The crack was probably associated with not surface grinding the two mold faces

completely parallel. A slight shrinkage occurred with the Devcon C after curing which in turn slightly raised up an area adjacent to the component cavity. After several injection cycles, the die was allowed to air cool in an attempt to reduce mold temperatures and keep mold temperatures constant.

A second epoxy mold was cast for the Safety Flag from REN RP3269-1. A straight through type water cooling channel was added to the upper and lower die plates of the four-plate die base in an unsuccessful attempt to reduce mold heat build-up during injection. Polyethylene was injected into this mold at 1750 psig at a nozzle temperature varying from 320°F to 350°F. Injection time varied from thirty to twenty seconds. Flash began appearing on the eighth piece with the epoxy runner eroding away. Injection was stopped on the eleventh trial with only a few acceptable components produced. Improper venting of the cavity which resulted in incomplete filling of the mold, incorrect injection parameters and erosion of the runner area required modifications in tooling and injection techniques.

Efforts to improve epoxy mold fabrication led to the discovery that the necessary technology and tooling for plastic injection epoxy molds is commercially* available. Molds that are capable of withstanding injection pressures of 12,000 psi and temperatures of 575°F have been fabricated on a commercial basis from Devcon C epoxy.

3.4 EPOXY MOLDS FOR RUBBER

Work prior to this project at Rock Island Arsenal with epoxy resins produced several successful compression molds. A single cavity mold for an M47 Tank Hose Collar, Part Number C7997755 shown in Figure 5 was cast from United States Gypsum Company S-408 Hy-Temp Surface Coat-Casting Resin with aluminum granules added for heat conduction. Rubber components were compression molded in heated molds at 307°F held under clamping pressure for thirty minutes. This mold produced over two hundred components before the mold cracked. The mold failure was attributed to not allowing sufficient mold heat-up time to allow for expansion rate differences between the aluminum die base and epoxy cavity to be reduced before compression molding.

The M47 Tank Shell Rack Spacer, Part Number B8742773, shown in Figure 6 and the M1912 Shotgun Butt Plate rubber components were also successfully produced in molds cast from the S-408 resin. Figure 7 shows the four cavity S-408 resin mold and a two cavity Devcon C resin mold for the Butt Plate. Although both molds produced acceptable parts, the S-408 epoxy resin was preferred because it could be cured at room temperature. A preferred method used to aid heat conduction in the epoxy mold was the addition of steel wool inserted into the mold cavity during casting instead of aluminum granules.

*Prototype & Plastic Mold Company, Rocky Hill, Connecticut

4. RESULTS

A fabrication cost comparison was made between the investment castment epoxy dies and engineering estimates for conventional metal dies and the results are tabulated in Table 3. The manhours to fabricate epoxy dies include:

1. Fabrication of an aluminum two-part die base with casting cavities.

2. Fabrication of a metal pattern and mounting plate for the pattern.

3. Casting and curing of the epoxy in the cavities around the pattern to produce the mold.

4. Any final machining of the mating mold surfaces parallel, runner, gates, air vents and subsequent metal inserts or mandrels.

A labor savings between 30% and 80% with a corresponding cost savings was realized by the application of epoxy tooling technology is this example. Resultant savings are dependent upon part configuration and the degree of difficulty to diesink the mold cavity. For component geometry and production order sizes that lend themselves to this technique, savings may be greater. The differences in material costs for epoxy molds and conventional molds is insignificant when compared to the labor savings resulting from epoxy tooling. Because of the initial successful results obtained from the fabrication of epoxy molds, the method was immediately incorporated as a production technique. Many molds for investment casting were subsequently produced by using epoxy tooling. These savings are also representative of fabrication costs for epoxy and rubber compression molds for short run production of 200 components or less.

5. CONCLUSION

The results obtained from this project demonstrated that small individual components for prototype or short-run production work could be successfully produced in epoxy molds. The actual number of components that can be produced for investment wax injection, plastic injection or rubber compression molding is dependent upon the mold cavity detail, injection material and injection conditions. For relatively simple pattern configurations for wax injection, as many as eight thousand patterns can be produced from one mold. The number of plastic components produced in epoxy molds is limited to only a few hundred pieces. Useful application of epoxy tooling for rubber compression molding is limited to the production of a few hundred pieces.

Epoxy molds can be produced at a substantial cost savings in comparison to conventional diesinking methods. Application of epoxy tooling is most beneficial in the area of investment casting pattern production.

The resin mold technique is especially advantageous for: (1) prototype runs, (2) low production runs, (3) parts for which a male prototype model may already exist, and (4) parts for which a male pattern is inherently easier to make than a female die.

A Comparison of Properties Between DEVCON C and REN RP3269-1

Tooling Expoxies

	Physical Properties	DEVCON C	REN RP-3269-1
1.	Impact lf+-lb in of notch IZOD	0.80	--
2.	Compression Ultimate PSI	30,000	27,600
3.	Tensile Ultimate PSI	9,000	7,300
4.	Modulus Elasticity in Tension PSI	1.20×10^5	--
5.	Flexural Ultimate PSI	19,000	11,600
6.	Hardness Shore D	89	90
7.	Thermal Expansion cm/cm/°c	45×10^{-6}	3.70×10^{-5}
8.	Thermal Conductivity cal/sec/cm/°c/cm^2	2.33×10^{-3}	----
9.	Specific Gravity	1.8	1.70
10.	Adhesive Tensile Shear (PSI)	2,700	----
11.	Cure Shrinkage In/In	0.001	0.0014
12.	Viscosity with Hardener cps	10,000 @ 212°F	4,600
13.	Pot Life of Lb. in Min.	45 @ 212°F	150
14.	Cubic In. per LB.	15.5	16.3
15.	Temperature Resistance F.	400°	143°
16.	Volume Resistivity ohm/cm	2 x 10"	----
17.	Surface Resistivity ohm	8×10^{10}	-----
18.	Dilectric Constant	21.4	-----
19.	Loss Tangent	0.08	-----
20.	Dilectric Breakdown Volts/mil.	50	-----

Table 1

Epoxy Molds for Investment Casting

	Part No.	Description
1.	F8448769	Pawl, Retaining
2.	C7266831	Nut, Regulator Lock
3.	C7792832	Button (M219)
4.	C77935540	Buffer
5.	D11013425-MP	Brace (M219)
6.	C1089399-1A	Acctuator
7.	105D3034-1	Lug
8.	9198702	Block, Humping
9.	D7792898	Pawl, Feed
10.	B11578599	Trunion
11.	- - - -	Front Sight (.45 cal)
12.	D12003040-1	Retainer, Front
13.	1006430-2	105D3031-1
14.	C11578603	Trigger
15.	7266361	Hammer
16.	C11578599	Lever, Bolt
17.	C8428053-7	Link

Table 2

FABRICATION MANHOUR COMPARISON
FOR INVESTMENT CASTING MOLDS

Component Name	Component Number	Conventional, Machined Dies (Est.) (Hrs.)	Epoxy Resin Molds (Hrs.)
1. Brace Receiver	11013425	140	80
2. Humping Block	9198702	200	140
3. Button	7792832	300	100
4. Retainer, Front	12003040	200	40
5. Collar	12003042	250	110
6. Pawl, Feed	7792898	350	150 *
7. Lever, Solenoid	11013417	225	110 *
8. Pawl, Retaining	8448769	250	90
9. Hammer	7266361	220	100
10. Regulator Lock Nut	7266831	210	120

*Engineering estimates

Table 3

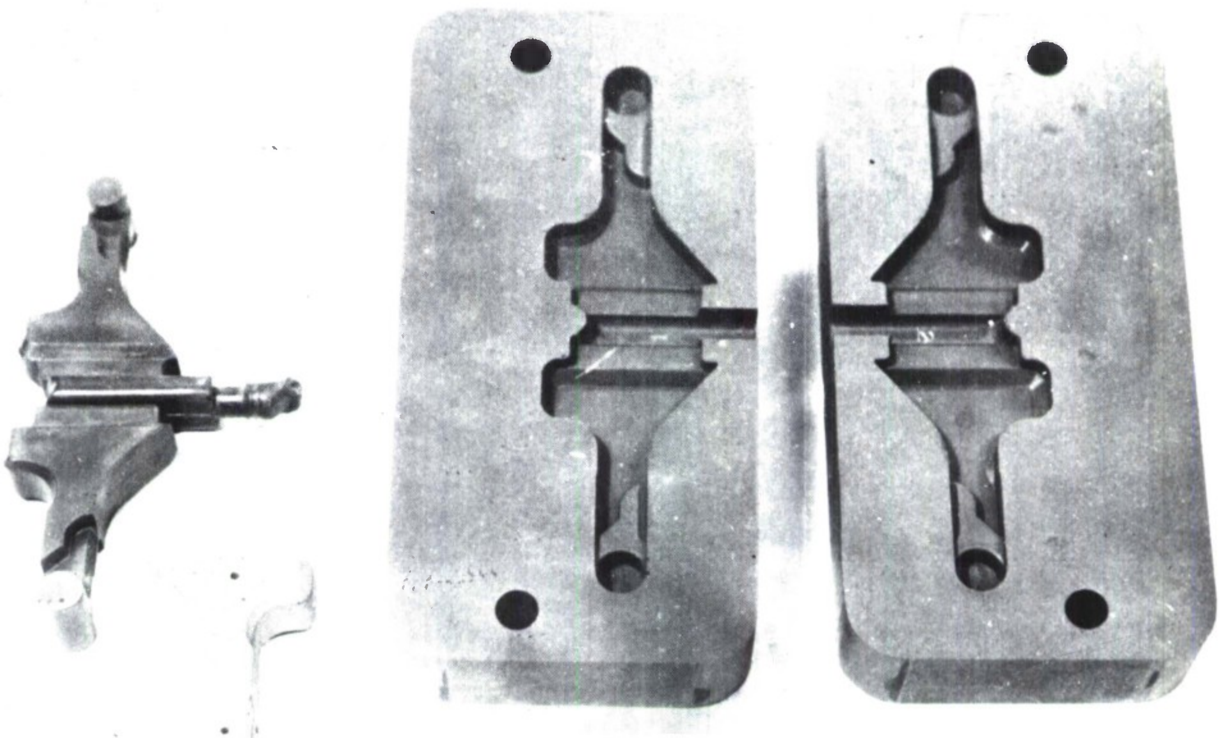

Figure 1. Devcon Plastic Steel B epoxy mold, investment wax patterns and cast component for the M8C Spotting Rifle Hammer, PN7266361.

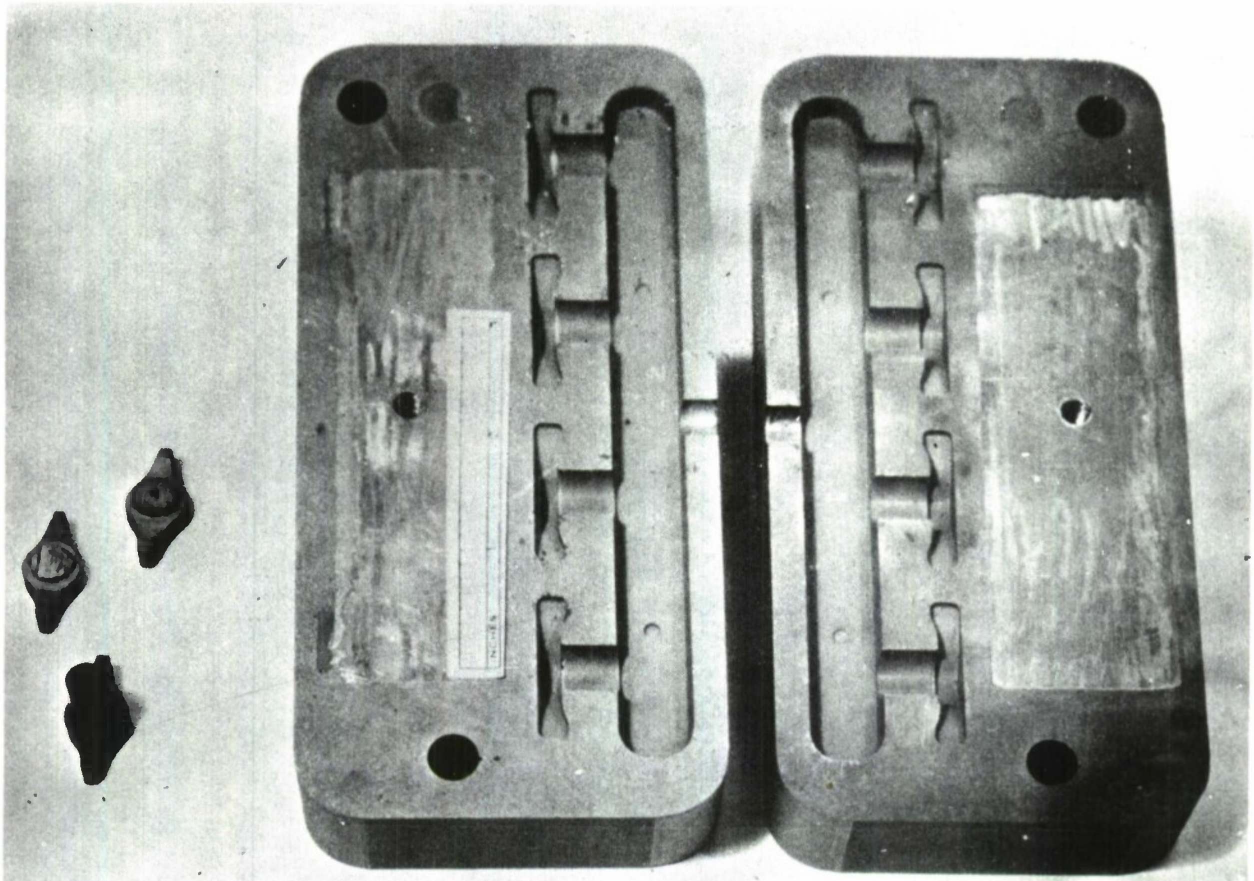

Figure 2. Devcon C epoxy mold, investment wax pattern and cost components for the M8C Spotting Rifle Regulator Lock Nut, PN 7266831.

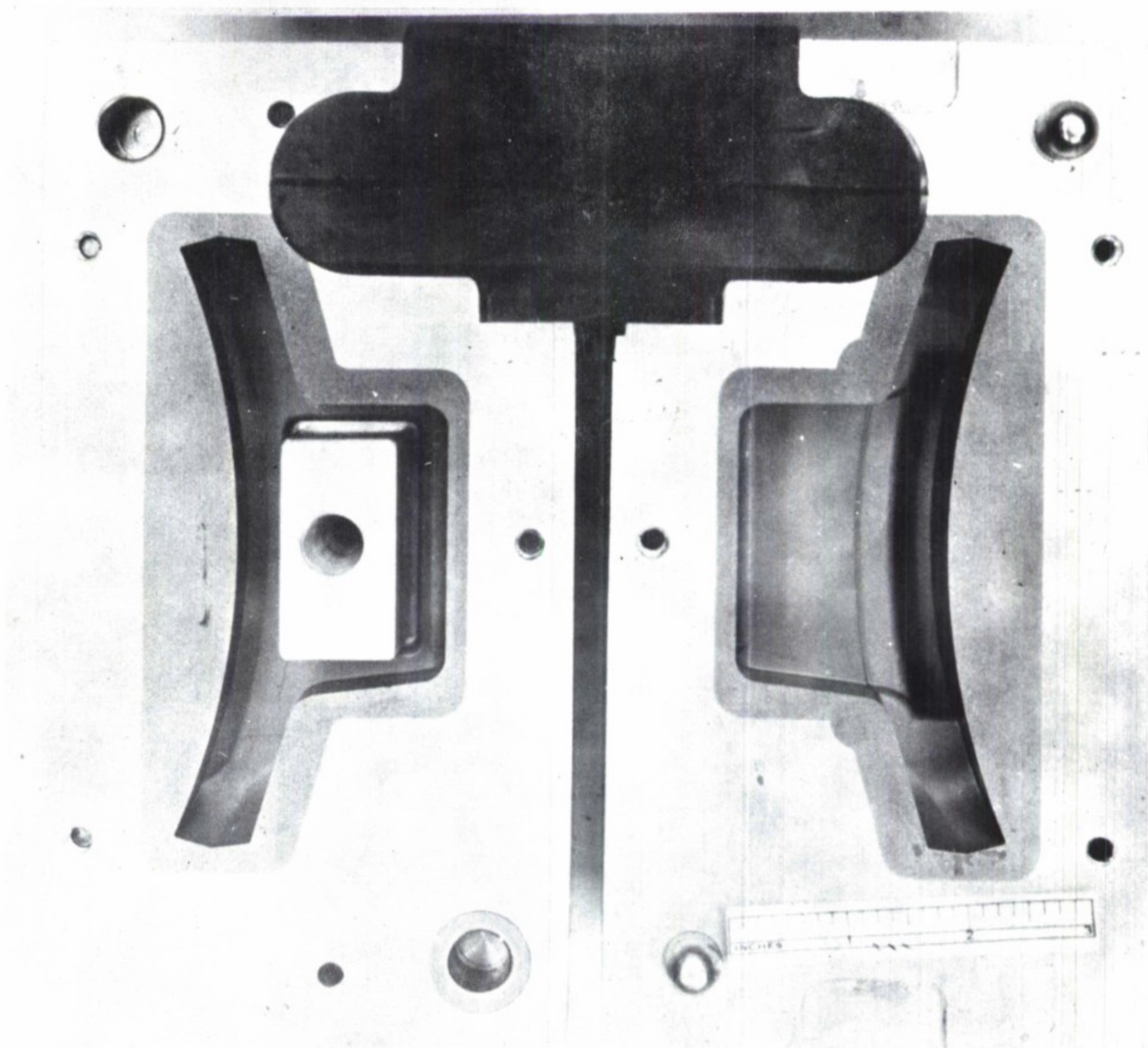

Figure 3. REN RP3269-1 epoxy mold with aluminum die base and investment wax pattern for the Humping Block, PN 9198702

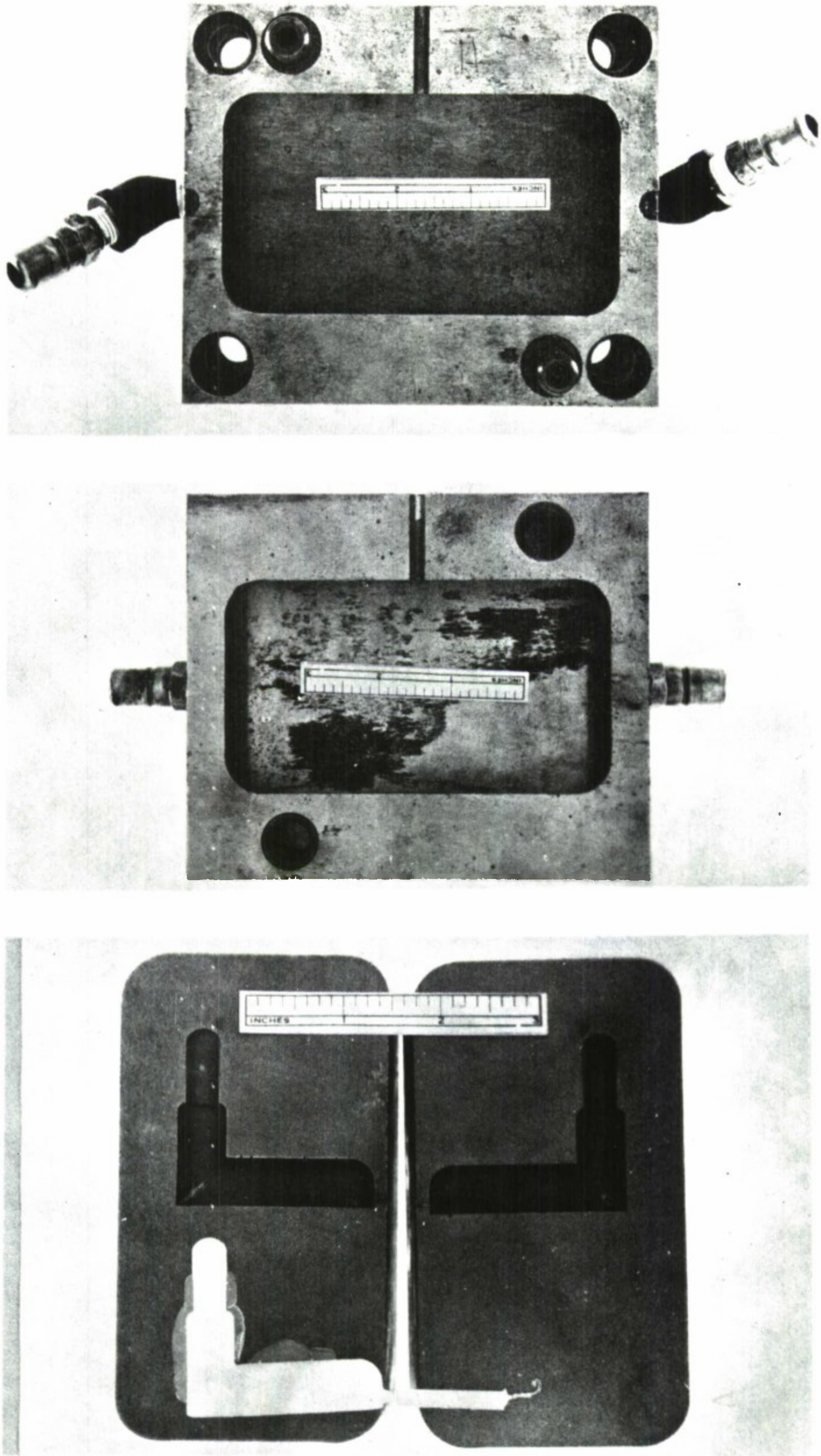

Figure 4. Standard steel D-M-E die base with cooling channels (upper and middle photographs) and REN RP3269-1 epoxy mold with polyethylene component produced for the M16 Rifle Safety Flag, PN 8448666.

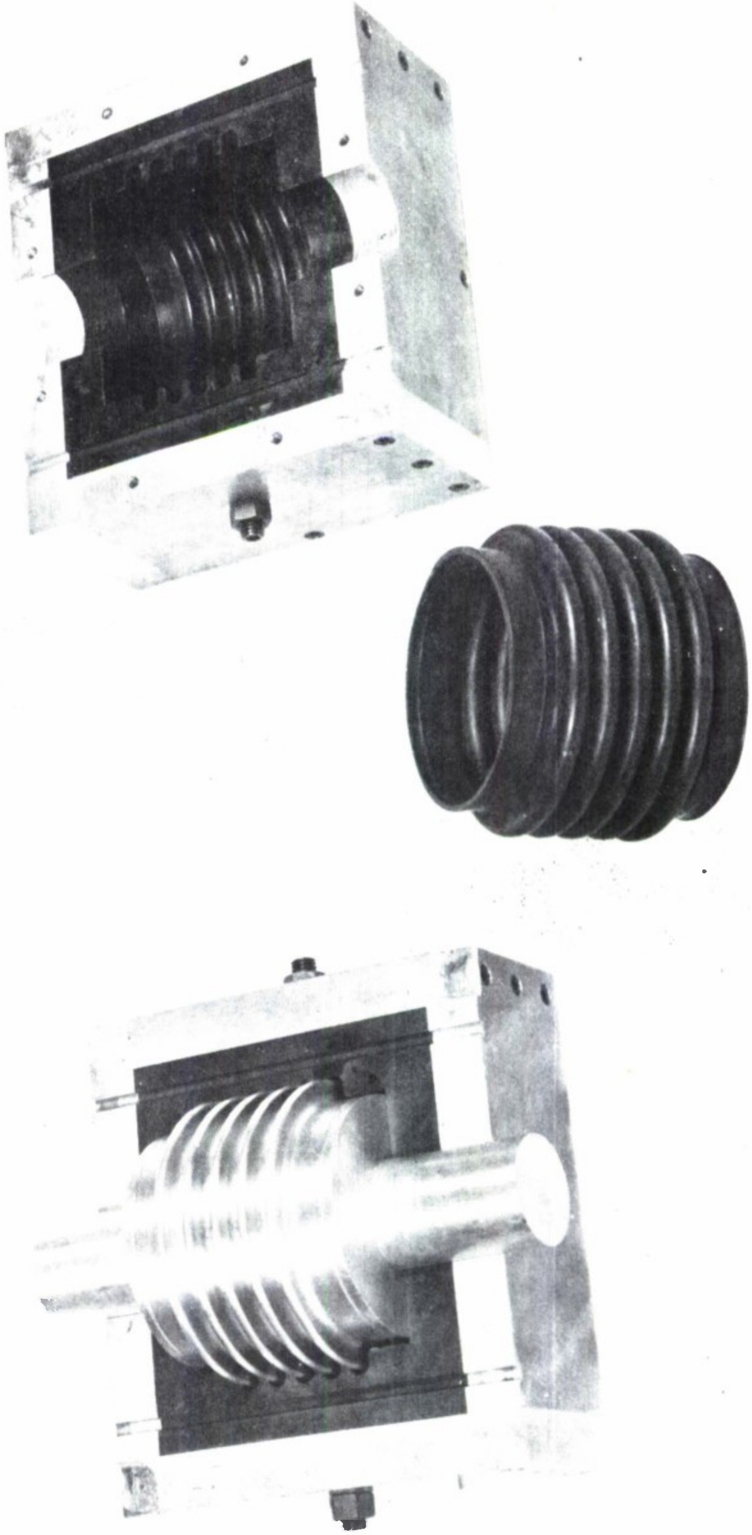

Figure 5. U. S. Gypsum Company S-408 Hy-Temp Surface Coat-Casting Resin epoxy mold with aluminum die base, mandrel and compression molded rubber component for the M47 Tank Hose Collar, PN C7997755.

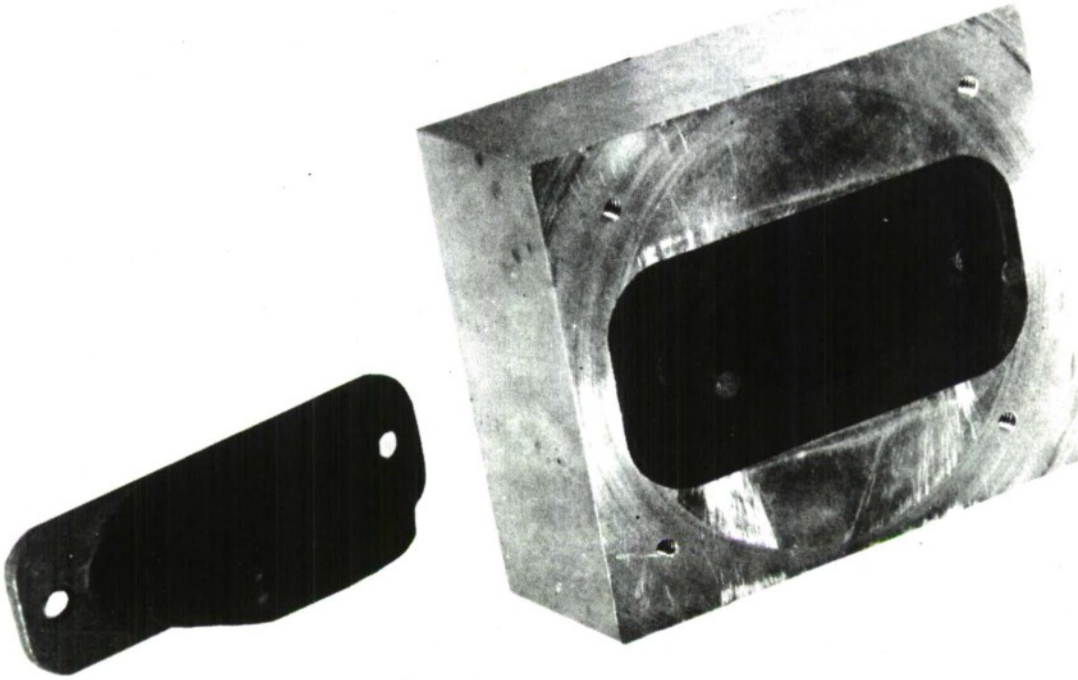

Figure 6. U. S. Gypsum Company S-408 Hy-Temp Surface Coat-Casting Resin epoxy mold and compression molded rubber component for the M47 Tank Shell Rack Spacer, PN B8742773.

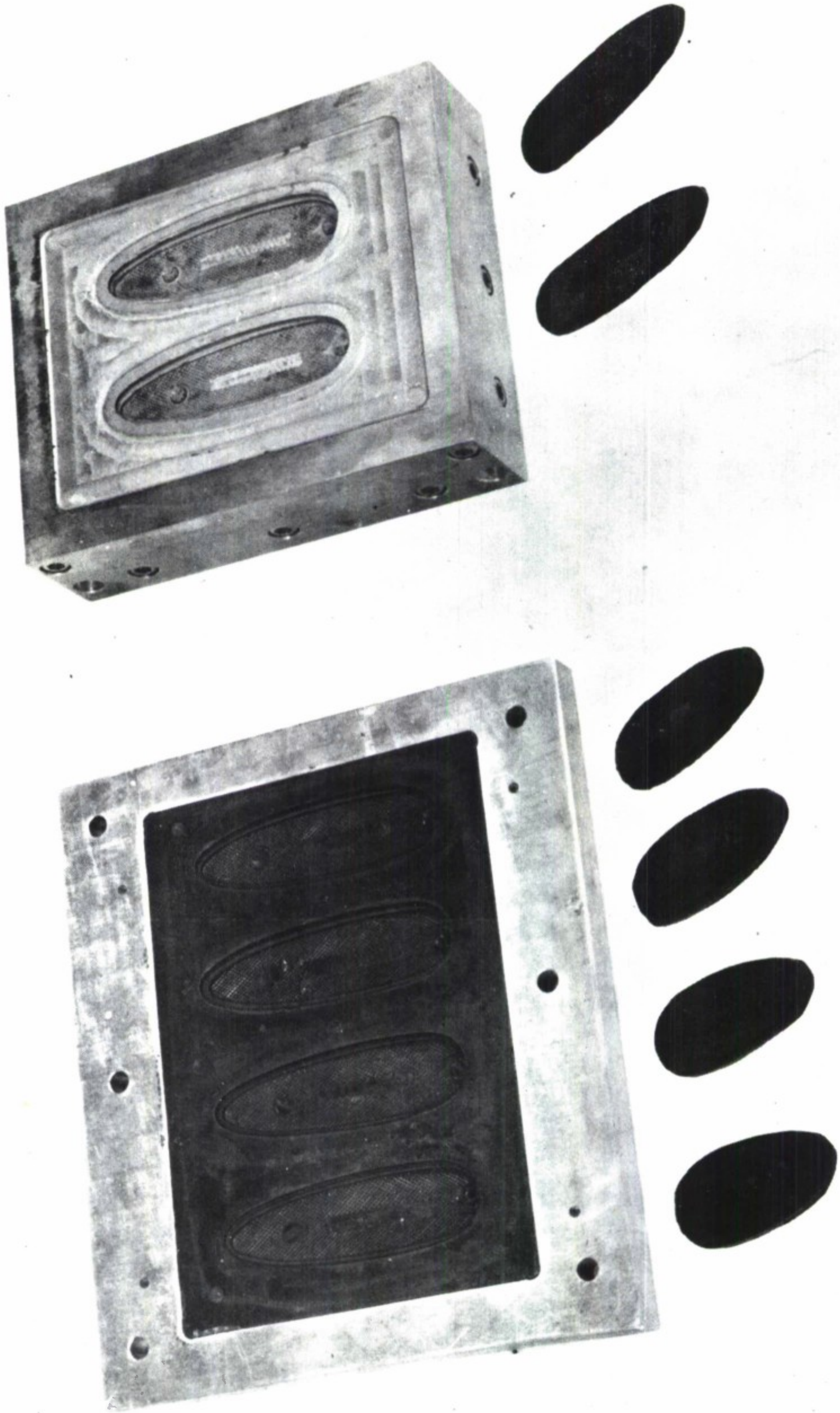

Figure 7. U. S. Gypsum Company S-408 Hy-Temp Surface Coat- Casting Resin four cavity mold (right) and Devcon C two-cavity mold (left) with compression molded rubber components for the M1912 Shotgun Butt Plate, PN 7311016.

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